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(19)

(54) IMPROVEMENTS IN OR RELATING TO OPTICAL SYSTEMS

(71) We, REDIFON LIMITED, a British company, of Carlton House, Lower Regent Street, London, S.W.1., do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to optical systems for the modulation of light of one or more selected wavelengths in a polychromatic light beam.

The present invention is particularly useful in optical systems wherein separate modulation of different colours in a polychromatic light beam is effected by spatially separating polychromatic light into separate colour components following separate paths, each of which includes a separate light-modulating device, and by then recombining the modulated components into a single beam again.

The object of the invention is to provide improved, separate-colour, light-modulating systems.

Accordingly, an optical system comprises, in combination, means for providing plane polarised radiation of one or more first radiation wavelengths along a first path and for providing plane polarised radiation of one or more second radiation wavelengths along a second path, first and second electro-optic intensity modulators included in said first and second paths, respectively, a polarisation responsive beam combiner for combining said first and second paths into a single path; and, located in said single path, a plate of birefringent material, of plate thickness such that, for one or more first radiation wavelengths, each said plate acts substantially as a wholewaveplate, and, for one or more second radiation wavelengths, each said plate acts substantially as a half-waveplate; whereby, for said first radiation wavelength or wavelengths, the plate does not affect the state of polarisation regardless of the orientation of the plate; and whereby for said second wavelength or wavelengths the plate alters the polarisation direction of transmitted plane polarised radiation components, according to the orientation of the plate with respect to the polarisation direction, and such but the polarisation directions of the first and second wavelengths in said single path are rendered parallel.

The invention may with advantage be applied to visual display systems in which a picture is built up by scanning an intensity modulated laser beam across a light-diffusing surface. Such display systems have been described as "laser television".

In such systems, colour is provided in the display by using a polychromatic laser beam in which different colours are seperately intensity modulated. Normally, three video signals are provided, corresponding respectively to the red, green, and blue components of the required picture. These signals are each used to drive one of three electro-optic intensity modulation cells. Through these cells are passed respectively, a red laser beam, a green laser beam and a blue laser beam. After separate modulation, the three laser beams are combined to form a single polychromatic beam, which is then scanned over a viewing screen.

Typically, the red beam is provided by a Krypton ion laser, (which however is also capable of providing all three required colours simultaneously), while a mixture of green and blue light is provided in the beam from an Argon ion laser.

In known laser television systems, it has been the practice to separate the blue and green components of the Argon laser beam, for separate intensity modulation. Two methods have been used for separation of different colour components of a polychromatic beam, for example for separating the blue and green components of an Argon laser beam. These are: First, the use of dispersing prisms, and Second, the use of thin film beam-spiltting mirrors. Dispersing prism devices may be made efficient, but are necessarily complex and bulky and are relatively difficult to keep in adjustment. This film beam-splitting mirrors are normally made dichroic, in the application under consideration, to maximise their reflection for one

colour and their transmission for the other. However, when the colours to be separated have similar wavelengths, as do the Argon laser blue and green components, dichroic mirrors are inefficient and provide an incomplete colour separation.

The known method of prism dispersion may also be used in the combination of beams after separate modulation. However, dichroic mirrors have usually been preferred for this purpose, due to the aforementioned disadvantages of prism dispersion devices. Dichroic mirrors used for combination of different colours are again inefficient where the colours to be combined have similar wavelengths, in this case a large proportion of light being lost.

In order that the invention may be fully understood and be readily carried into practice, three known beam-splitting arrangements and an embodiment of the invention will now be described in detail, the latter by way of example, with reference to the accompanying drawings, in which:

Fig. 1 shows a known beam-splitting arrangement using a birefringent plate and a Wollaston prism;

Fig. 2 shows a known arrangement using a birefringent plate and a polarising beam-splitter;

Fig. 3 shows a known beam-combining arrangement using the birefringent plate and Wollaston prism of the arrangement of Fig. 1, in reverse; and

Fig. 4 is a perspective schematic diagram showing an optical system according to the present invention for separately modulating three colour components and for combining the modulated components into a modulated polychromatic beam.

In three known beam-splitting devices, there is provided a plate of birefringent material on which a plane polarised beam of radiation is incident. The optic axis of said plate is oriented substantially at 45° to the plane of polarisation of the incident beam and the thickness of the plate is such that, for one or more first radiation wavelengths, the plate acts substantially as a whole-waveplate, which for one or more second radiation wavelengths, the plate acts substantially as a half-waveplate. Thus, for said first wavelength or wavelengths, the polarisation direction of the transmitted radiation is unchanged, while, for said second wavelength or wavelengths, the polarisation direction of the transmitted radiation is substantially effectively rotated through 90°. The plate is followed in the radiation path by a beam splitting element which divides the incident radiation into two separate paths according to the polarisation of the radiation. This element is oriented so that the component of radiation incident on it which has the polarisation direction associated with said first wavelengths, is substantially directed into a first path, while the component of radiation incident on it which has the polarisation direction associated with said second wavelengths, is substantially directed into a second path.

A first such known arrangement is illustrated in Fig. 1, in which diagram the birefringent plate is a plane parallel, polished disc of crystalline quartz 10, the optic axis 11 of which is parallel to the flat faces of the plate. A polychromatic laser beam, 12, is transmitted through the plate 10, travelling at right angle to the flat faces. The incident beam 12 is polarised in the direction indicated by the arrow 13, which is at 45° to the optic axis of the quartz disc 10. After leaving the quartz disc 10, the laser beam 12′ is passed into a Wollaston prism 14A.

A Wollaston prism is a well-known device for resolving an incident beam into two components, plane polarised at right angles to each other, these two components being deflected by different angles from their initial direction. In the arrangement of Fig. 1, the Wollaston prism 14 is oriented so that the polarisation directions of the two emergent beams 15 and 16, into which the prism 14 divides the incident beam 12′ are, respectively, the polarisation direction of the beam 12 before entering the quartz plate and the orthogonal direction.

It is assumed that the polychromatic incident beam 12 contains components of wavelengths λ_1, λ_2 etc. and λ_1^1, λ_2^1 etc., that all these components are plane polarised in one direction, and that it is required to divide the beam into two separate beams, the first containing only the wavelengths λ_1, λ_2 etc., and the second containing only the wavelengths λ_1^1, λ_2^1 etc. For each wavelength of radiation, the quartz disc 10 has two refractive indices, known as the ordinary and the extraordinary, corresponding to two different radiation propagation velocities, one velocity for the component polarised parallel to the optic axis and the other velocity for the component polarised at right angles to the optic axis. The difference of these refractive indices, (Δn_1 for λ_1, Δn_2 for λ_2 etc., and Δn_1^1 for λ_1^1, Δn_2^1 for λ_2^1 etc), with the thickness of the plate, may be used to calculate the distance by which the slow component is retarded with respect to the fast component, due to the plate, when the beam emerges from the plate. If the thickness of the plate is t, then the retardation is:

$$t\,.\,\Delta n_1 \text{ for } \lambda_1,\ t\,.\,\Delta n_2 \text{ for } \lambda_2 \text{ etc, and}$$

$$t\,.\,\Delta n_1^1 \text{ for } \lambda_1^1,\ t\,.\,\Delta n_2^1 \text{ for } \lambda_2 \text{ etc.}$$

Now, if the retardation is substantially equal to a whole number of wavelengths, the two components emerge in phase, and the polarisation state of the emerging radiation

is substantially the same as that of the incident radiation. If the retardation is substantially equal to a whole number of wavelengths plus a half wavelength, the two components emerge 180° out of phase, and the polarisation state of the emerging radiation is substantially plane polarised at right angles to the polarisation of the incident beam. In this latter case, the plate acts as a half-waveplate, which has the effect of effectively rotating the polarisation direction of the incident radiation through an angle equal to double the angle between the initial polarisation direction and the optic axis. The thickness of the plate is selected so that the ratios:

$$\frac{t \,.\, \Delta n_1}{\lambda_1} \qquad \frac{t \,.\, \Delta n_2}{\lambda_2}$$

etc are approximately equal to whole numbers, while the ratios:

$$\frac{t \,.\, \Delta n_1{}^1}{\lambda_1{}^1} \qquad \frac{t \,.\, \Delta n_2{}^1}{\lambda_2{}^1}$$

etc are approximately equal to whole numbers plus 0.5. Thus, the radiation of wavelengths λ_1, λ_2 etc. is not substantially affected by the quartz plate 10 and is deflected into path 15 by the Wollaston prism, while radiation of wavelengths $\lambda_1{}^1$, $\lambda_2{}^1$, etc. leaves the quartz plate substantially with a 90° rotation in polarisation and this radiation is deflected into path 16 by the Wollaston prism.

A second known beam-splitting arrangement is shown in Fig. 2. The arrangement is identical to that shown in Fig. 1, except that the Wollaston prism 14 of Fig. 1 is replaced by a polarising beam splitter shown at 20 in Fig. 2. The beam splitter 20 has a semi-reflecting mirror layer 21, consisting of multiple thin films of dielectric material, designed to reflect radiation polarised in a direction parallel with the layer, while transmitting radiation polarised in the orthogonal direction. Such beam splitters are well-known and may be highly efficient in dealing with radiation within a limited wavelength range. As in Fig. 1, reference numerals 10, 11, 12 and 13 are used to indicate respectively, a disc of crystallizing quartz, its optic axis, a polychromatic laser beam and its polarisation direction. The quartz disc 10 rotates the polarisation of radiation of selected wavelengths, as before, while not affecting the polarisation of other wavelengths in the emergent beam 12′. The two groups of wavelengths are then separated at the beam splitter 20 into paths 22 and 23.

In a known beam-combining device there is provided a plate of birefringent material having properties with respect to radiation of first and second radiation wavelengths as specified for the plate provided in Fig. 1. There is further provided a beam combining element which deflects incident radiation into a single path from either one of two paths of incidence, the first path being preferred for plane polarised radiation of a first polarisation direction, and the second path being preferred for plane polarised radiation of a second, orthogonal polarisation direction. Radiation of said first wavelength or wavelengths is plane polarised in said first polarisation direction and directed onto the beam combiner in said first path, while radiation of said second wavelength or wavelengths is polarised in the orthogonal polarisation direction and directed onto the beam combiner in said second path, so that the two radiation components are efficiently combined into a single beam. Said plate of birefringent material is placed in the combined beam with its optic axis at 45° to the directions of polarisations of both components, so that the direction of polarisation of said second wavelength or wavelengths is rotated through 90° to match the polarisation of said first wavelength or wavelengths and form a combined beam of unified polarisation.

Such a known arrangement is shown in Fig. 3. The arrangement there shown is identical to that shown in Fig. 1, except that the light paths are reversed. As in Fig. 1, reference numerals 10, 11 and 14 are used to indicate, respectively, a crystalline quartz plate, its optic axis, and a Wollaston prism. A first incident beam 30, containing wavelengths λ_1, λ_2 etc., is polarised as indicated by the arrow 31. A second incident beam 32, containing wavelengths $\lambda_1{}^1$, $\lambda_2{}^1$ etc., is polarised in the orthogonal direction indicated by the arrow 33. The two beams meet in the Wollaston prism 14, which is oriented to deflect both beams, by virtue of their polarisation directions, into a single emergent beam 34. The beam 34 passes into the plate of quartz 10 which has its optic axis at 45° to both polarisation directions of the incident beam. The thickness of the plate 10 is selected, as before, so that it acts as a whole-waveplate for wavelengths λ_1, λ_2 etc. and as a half-waveplate for wave-lengths $\lambda_1{}^1$, $\lambda_2{}^1$ etc. The plate 10 therefore alters the polarisation directions of wavelength components $\lambda_1{}^1$, $\lambda_2{}^1$ etc. by 90°, while not affecting the polarisation of component λ_1, λ_2 etc. thus converting the beam 34 to a simple plane polarised emergent beam 34′.

Use of a polarisation responsive beam combiner, such as a Wollaston prism, to give efficient combination of orthogonally polarised beams is not novel in itself.

In the present invention a birefringent plate is used in cases where the two plane polarised beams of different wavelength composition, are separately intensity modulated before being incident on a polarisation respon-

sive beam combiner, to render parallel, the polarisation directions of transmitted components of the combined beam. This alignment of polarisation is not always essential, but is occasionally desirable, for example when there is a preferred direction of polarisation in the following optics. When a third beam of radiation is to be combined with already-combined first and second beams, an efficient polarising beam combined can only be used if the first and second components have the same polarisation direction.

Fig. 4 shows a practical embodiment of the present invention.

In Fig. 4, an argon ion laser 40 produces a plane polarised beam 41 of light, including green light of wavelength 514 nm and blue light of wavelength 488 nm. The beam 41 is passed through a crystalline plate 42, having its optic axis 43 at 45° to the direction of polarisation of the incident beam, indicated by the arrow 44. The plate 42 is polished to a thickness of 0.446 mm, so that the retardation for the green component is 8.00 wavelengths, and the retardation for the blue components is 8.49 wavelengths. The plate 42 is thus a whole waveplate for green light and transmits it without a net change in polarisation state. The plate 42 is substantially a half waveplate for the blue component and effectively alters its direction of polarisation by 90°. The plate 42 is followed by a polarization responsive beam splitter 45 with a face 46 set at 45° to the incident beam 41′ and which transmits the light polarised in the plane of incidence and reflection, and reflects the orthogonally polarised light. The beam splitter 45 is set to transmit the green light 41G and reflect the blue 41B. The separated blue component 41B is deflected parallel to the original path by a prism 47. Both components then pass through electro-optic intensity modulators 48 and 49. Each modulator 48, 49 is a Pockel cell followed by an analyser, the analyser being oriented, as is usual, to transmit light polarised at 90° to the polarisation direction of light incident on the cell. The emergent green beam 41G′ is deflected by a prism 140 to meet the emergent blue beam 41B′ in a beam combiner 141, identical in construction to the beam splitter 45, so that the blue beam is transmitted and the green beam reflected, the two beams being recombined at 41″. A second crystalline quartz plate 142, identical in construction to the first plate 42, and similarly oriented, is placed in the recombined beam 41″ and alters the polarisation of the blue component so that it is parallel to that of the green, and so that the beam is now entirely plane polarised at right angles to the initial direction.

A krypton ion laser 143 provides a beam 144 of red light which is modulated by an electro-optic cell 145. The modulated red beam 144′ has a direction of polarisation orthogonal to that of the recombined blue/green beam. It intersects with the blue/green beam at a beam combiner 146, identical in construction to the beam splitter 45, so that the blue/green beam is reflected and the red transmitted, the two beams being combined at 144″.

It should be noted that, although the practical embodiment described relates to apparatus for dealing with visible laser light, the invention may be applied to apparatus for dealing with laser radiation outside the visible spectrum.

Further, the electro-optic cells used in the practical arrangements described may be either Pockel cells or Kerr cells, as preferred.

WHAT WE CLAIM IS:—

1. An optical system comprising, in combination, means for providing plane polarised radiation of one or more first radiation wavelengths along a first path and for providing plane polarised radiation of one or more second radiation wavelengths along a second path, first and second electro-optic intensity modulators included in said first and second paths, respectively, a polarisation responsive beam combiner for combining said first and second paths into a single path; and, located in said single path, a plate of birefringent material, of plate thickness such that, for one or more first radiation wavelengths, each said plate acts substantially as a whole-waveplate, and, for one or more second radiation wavelengths, each said plate acts substantially as a half-waveplate; whereby, for said first radiation wavelength or wavelengths, the plate does not affect the state of polarisation regardless of the orientation of the plate; and whereby, for said second wavelength or wavelengths the plate alters the polarisation direction of transmitted plane polarised radiation components, according to the orientation of the plate with respect to the polarisation direction, and such that the polarisation directions of the first and second wavelengths in said single path are rendered parallel.

2. An optical system comprising, in combination, first and second plates of birefringent material of plate thickness such that, for one or more first radiation wavelengths, each said plate acts substantially as a whole-waveplate, and, for one or more second radiation wavelengths, each said plate acts substantially as a half-waveplate; whereby, for said second wavelength or wavelengths the plate alters the polarisation direction of transmitted plane polarised radiation components, according to the orientation of the plate with respect to the polarisation direction; and whereby, for said first radiation wavelength or wavelengths, the plate does not affect the state of polarisation regardless of the orientation of the plate; a polarisation responsive beam splitter, positioned after the first said plate

and adapted to split transmitted radiation along first and second paths according to its polarisation; first and second electro-optic intensity modulators included in said first and second paths, respectively; and a polarisation responsive beam combiner for combining said first and second paths into an emergent single path; said second plate being located in said emergent single path and serving to render parallel the polarization directions of the first and second wavelengths.

3. An optical system as claimed in Claim 2, in which each said plate of birefringent material is a plane parallel plate of crystalline quartz having its optic axis parallel to the plate faces.

4. An optional system as claimed in Claim 2 or Claim 3, in which the polarising beam splitter is a Wollaston prism.

5. An optical system as claimed in Claim 2 or Claim 3, in which the polarising beam splitter has a semi-reflecting mirror layer.

6. An optical system as claimed in any one of the preceding claims, in which said first and second radiation wavelengths define first and second visible colours, separately modulated by said first and second modulators.

7. A laser television system including an optical system as claimed in any one of Claims 1 to 6.

8. An optical system as claimed in Claim 1, arranged substantially as described herein with reference to Fig. 4 of the accompanying drawings.

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1 409 711 COMPLETE SPECIFICATION
2 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

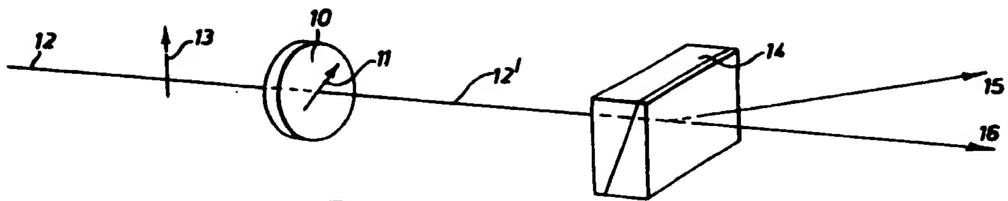

Fig.1.

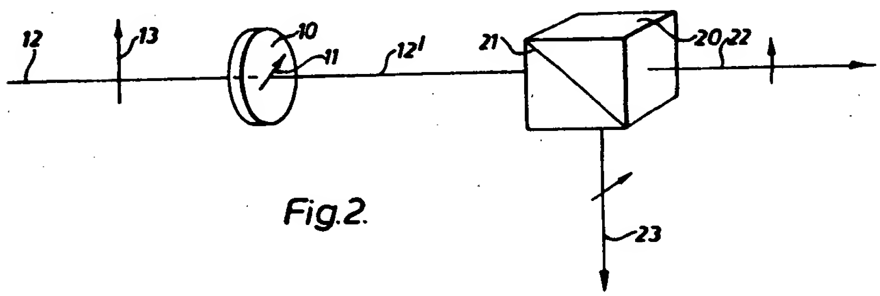

Fig.2.

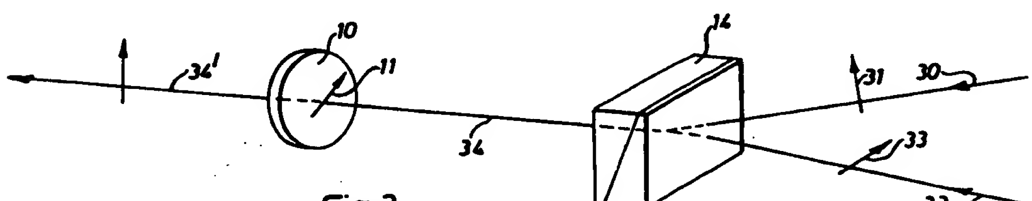

Fig.3.

1 409 711 COMPLETE SPECIFICATION
2 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEET 2

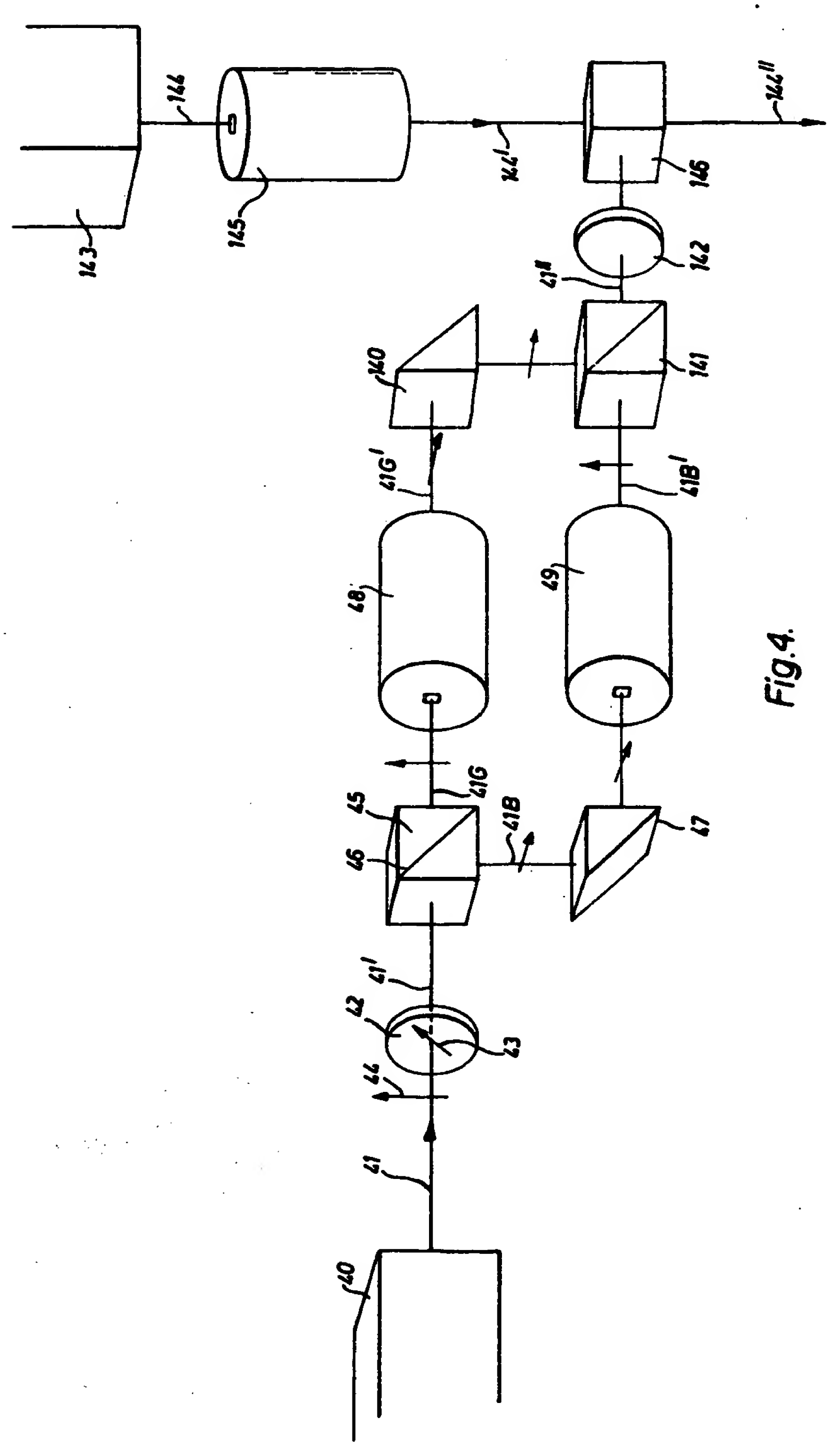

Fig.4.